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TITLE: Guns vs Bells – What's the Best Way to Apply My UV Cure Coating?

Synopsis/Abstract

If you believe that the selection of guns or bells for your UV coating application is based solely on transfer efficiency, you are only considering half of the picture. In this paper we examine some little-known facts about guns and bells — things that your supplier never told you — and how these "secrets" affect the application of coatings, specifically with regard to surface finish. In the end, we distill these factors into practical guidelines to help you select the best applicator for your project to more than double your chances to obtain your desired finish results with high first-pass yields and minimal finish-related rejects.

Introduction

The goal of any finishing operation – whether waterborne, solventborne, or UV Cure – is to apply a consistent and contiguous coating to the subject part. This coating serves many purposes:

1) Beautification to improve the aesthetic appearance of the part

2) Protection against such things as scratches, corrosion, UV damage, etc.

3) Improved performance in the part's final application. This can include such things as increasing resistance to moisture, reducing aerodynamic drag (i.e. – automobiles, airplanes, rockets), hydraulic drag (i.e. – boats, ships, torpedoes), and a host of others.

There are many ways to apply these coatings including dipping, brushing, rolling, flow coating, etc., but in this discussion, we are going to focus on spray operations.

In a spray operation, the coating is atomized into a pattern of droplets and applied to the surface of the part, where the droplets rejoin one another and flow out to form a film. The primary devices used to perform this atomization function are guns and bells.

Comparing Guns and Bells

Similarities

Because they both do the same job, it is easy to understand that there are many similarities between guns and bells. Both atomize the coating into a cloud, creating a fan pattern that can spread out over the surface of the target part.

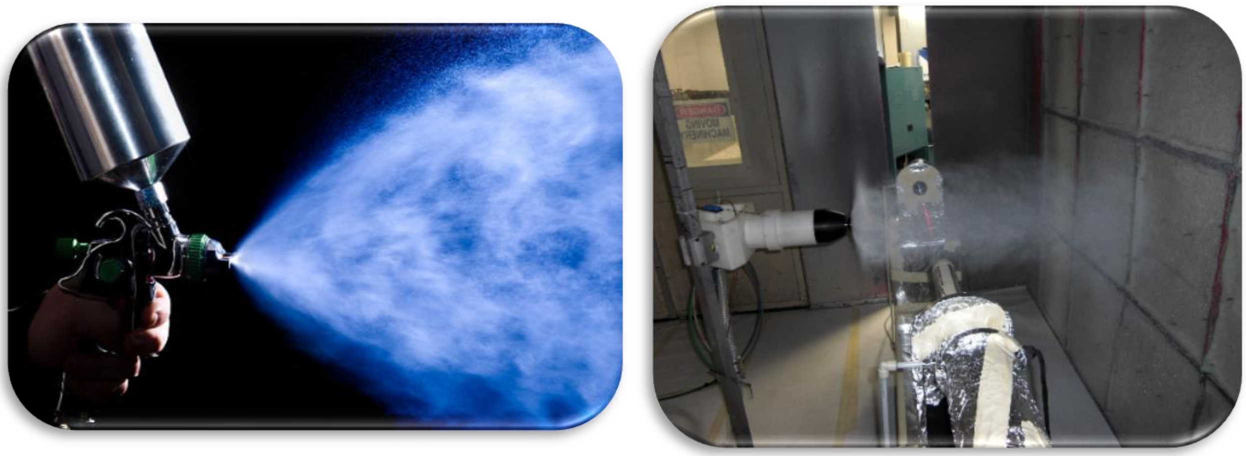

Figure 1: Gun[1] vs. Bell[2] Atomizers

Both use compressed air to “shape” the fan pattern. Both can be used in electrostatic applications, where the coating particles are charged at a high voltage and the part is grounded to create an “attraction” between the atomized droplets and the part. This helps to reduce overspray, get more of the liquid coating on the part, and increase transfer efficiency.

Differences

While both create a fan pattern, it is obvious from Figure 1 that the patterns created can be very different. This is due, in part, to the differences in the way that the atomized cloud is created. We will explore that in detail shortly...

Bells are larger and heavier than guns. This makes guns more suitable to manual spray applications, providing an operator greater control with less stress and fatigue. Bells are generally limited to robotic, reciprocator, or otherwise automated applications.

While any coating applicator is susceptible to maintenance and cleaning issues, bells are more complex, with lots of moving parts. In general, bells require more maintenance than guns.

Bells are generally used with lower viscosity fluids supplied at lower pressure, whereby guns may be better suited for higher viscosity, higher pressure applications. This is where we begin to see a distinction in applicator choice for UV Cure Coatings.

But first, let’s get back to atomization…

Atomization

Fundamentals

In short, atomization is the result of applying shear, which tears the fluid stream into a cloud of small particles.

The rotating cup on the bell generates shear in the fluid by adding force perpendicular to the direction of the fluid stream as it reaches the edge of the cup. The size of the particles is primarily determined by the design of the cup itself, the flow rate of the coating (which determines the rate at which fluid is delivered to the edge of the cup), and the speed of rotation (which determines the speed of the cup edge relative to the fluid stream). As a result, most of the energy imparted to the particle is perpendicular to the bell and parallel to the part. Without some means of directing the cloud, it would simply hover adjacent to the part with very little fluid actually reaching the surface. Thus, shaping air is used not only to "shape" the fan pattern, but also to direct it toward the part.

Guns, on the other hand, generate shear by reducing the diameter of the fluid stream – which increases its velocity – and then forcing it through a small orifice. The acceleration and compression breaks the fluid stream into small particles creating the atomized cloud. Atomization is controlled by the size and shape of orifice and the flow rate of fluid through it, which is generally a function of the characteristics (size and shape) of the flow path, the viscosity of fluid, and the pressure behind it. The fan pattern is also both shaped, and directed, by the shaping air, but because the fluid stream is already moving toward the part at a high velocity when it is atomized, guns create particles with a higher velocity toward the part than do bells.

Quantifying the Differences

So how do these differences in atomization affect our day-to-day coating operation? This was put to the test at Carlisle Finishing Technologies' lab in Toledo, OH, using their Malvern Particle Size Analyzer to measure the distribution of particle sizes in the atomized cloud for a typical gun and bell as shown in Figure 2.

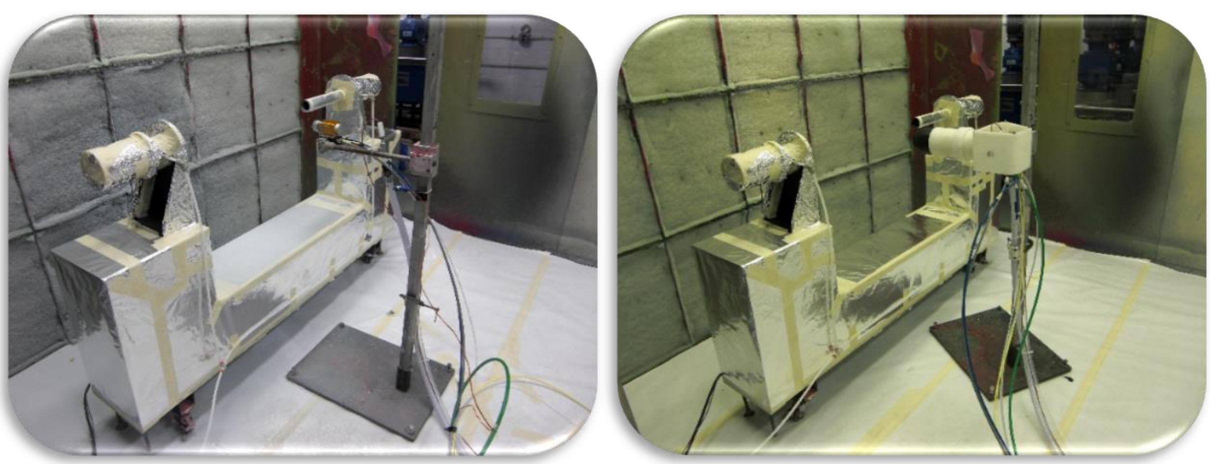

Figure 2: Cloud Measurement Setups

To maintain consistency, both gun and bell tests were performed using an HCNTX 2K clearcoat. Ratio, fluid flow, and atomizing and shaping air were all held constant with a Ransberg RCS system. Ambient conditions were simulated with a Saint Clair Systems coating temperature control system implemented with a re-corable coax hose as the heat exchanger. This configuration allowed accurate control of temperature all the way to the point of dispense in controlled, repeatable steps. This system is shown in Figure 3.

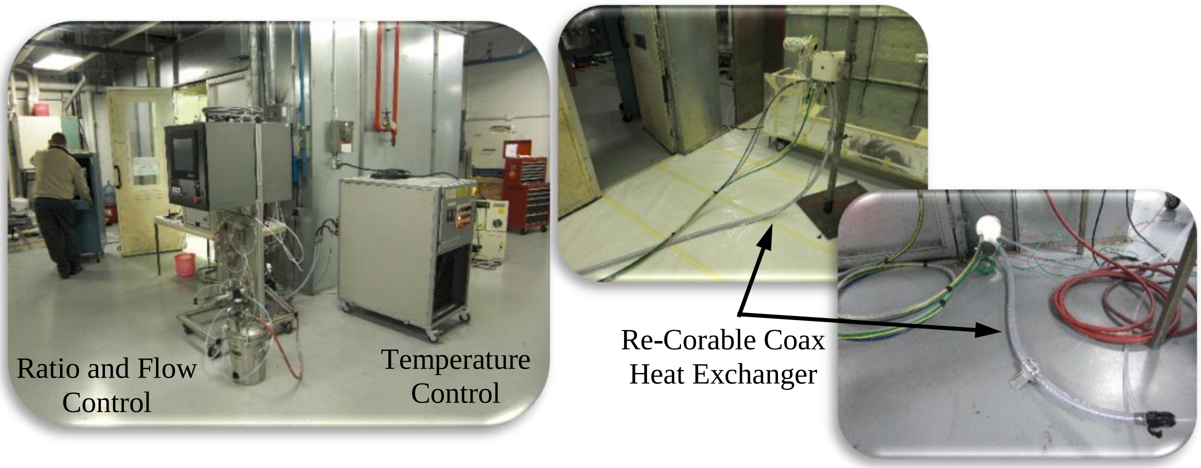

Figure 3: Test Control System

Gun Testing

Though sequence was not important, the first tests were performed with the gun setup shown in Figure 2. With all other parameters held constant by the RCS system, temperature was varied in controlled increments from 65°F - 115°F (18°C - 46°C) for the expressed purpose of varying clearcoat viscosity. At each step, the resulting Dv(50) average particle size in the atomized cloud was measured using the Malvern.

The results are summarized and shown in Figure 4. Here we can see that, with all other variables held constant, the average particle size for the gun applicator varied from 52.3µ at 65°F (18°C) down to 38.6µ at 115°F (46°C).

Based on the discussion of gun atomization above, it is reasonable to conclude that the change in atomization is directly related to the change in clearcoat viscosity resulting from the change in fluid temperature.

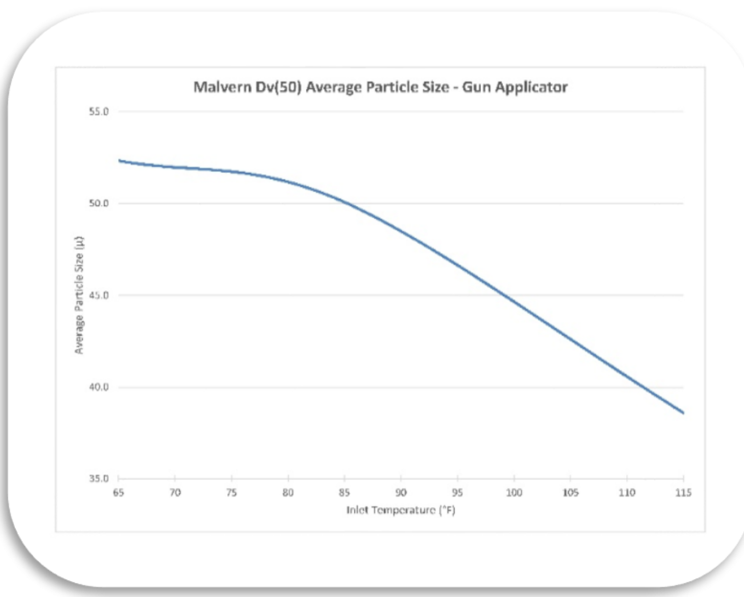

Figure 4: Gun Cloud Particle Size

In addition to variations in particle size, the change in viscosity will affect particle recombination and flow out on the surface of the part. This will have a direct impact on the quality of the finish with regard to film build, gloss, orange peel, etc.

Bell Testing

Next, the gun was replaced with a bell in the setup shown in Figures 2 and 3. The cup speed was set at 32,000 RPM, and, as with the gun, all other parameters were held constant by the RCS system. Temperature was again varied in controlled increments from 65°F - 115°F (18°C - 46°C) for the expressed purpose of varying clearcoat viscosity and, at each step, the resulting Dv(50) average particle size in the atomized cloud was measured using the Malvern.

The results are summarized and shown in Figure 5. Here we can see that, with all other variables held constant, the average particle size for the bell applicator held steady at ~27µ independent of the changes in temperature.

Based on the discussion of atomization above, it is also reasonable to conclude that bell atomization is not affected by the change in clearcoat viscosity resulting from the change in temperature.

This theory was confirmed by increasing the cup speed from 32,000 RPM to 60,000 RPM at the median temperature of 85°F. This shifted the average particle size from ~27µ to ~16µ.

Because these are both plotted on a 20µ particle size scale and a 65°F to 115°F temperature scale, they can be combined on the same graph, as shown in Figure 6. This allows us to readily compare the atomization performance as a function of temperature (viscosity) for the two applicator types.

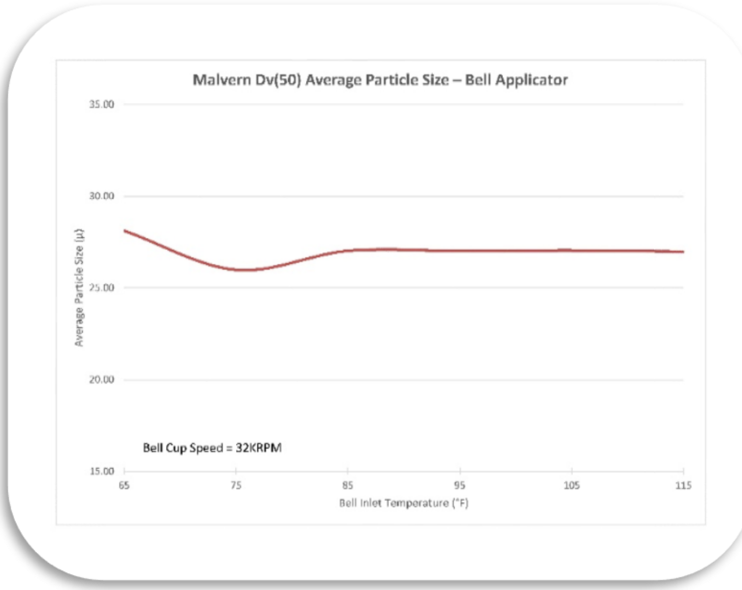

Figure 5: Bell Cloud Particle Size

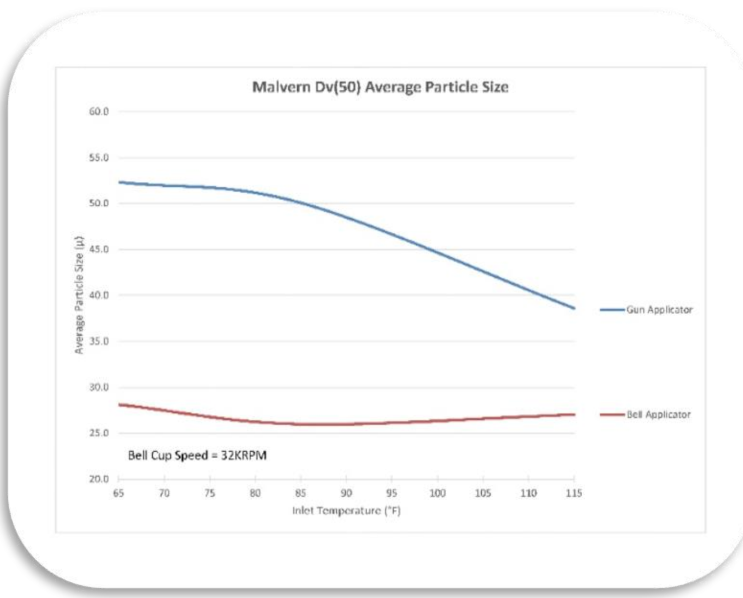

Figure 6: Cloud Particle Size Comparison

Though there is no change in particle size as a function of temperature with the bell applicator, the change in viscosity will still affect particle recombination and flow out on the surface of the part – just as with the gun applicator – and this will still have a direct impact on the quality of the finish with regard to film build, gloss, orange peel, etc.

Temperature as a Tool

Figure 7 shows the viscosity-temperature curve for a common solventborne paint. This shows the typical non-linear relationship associated with coatings over the normal ambient temperature range.

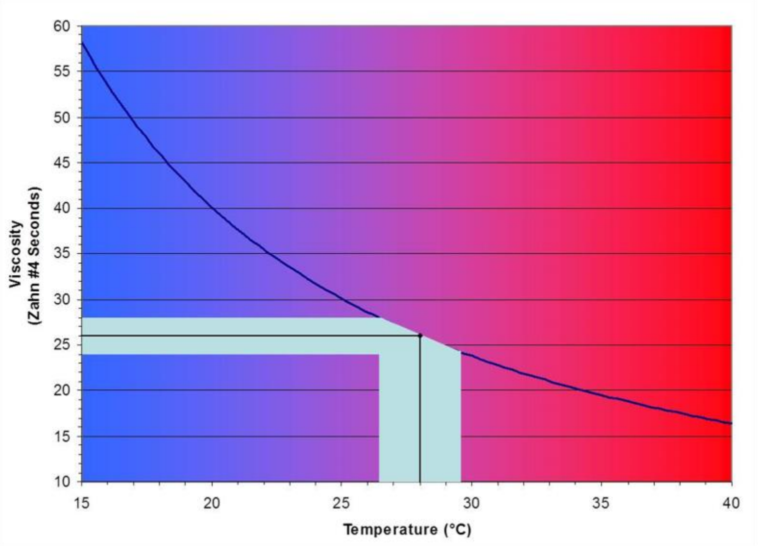

Figure 7: Paint Viscosity vs. Temperature[3]

The optimum coating viscosity for this material (26 ±2 seconds) is plotted on the graph to show its relationship to temperature. The entire acceptable viscosity range relates to a 3°C window from 26.5°C to 29.5°C (80°F – 85°F). If the paint temperature is outside of this narrow window, it will be outside of its optimal viscosity range and either the viscosity must be corrected or other process parameters must be adjusted to compensate.

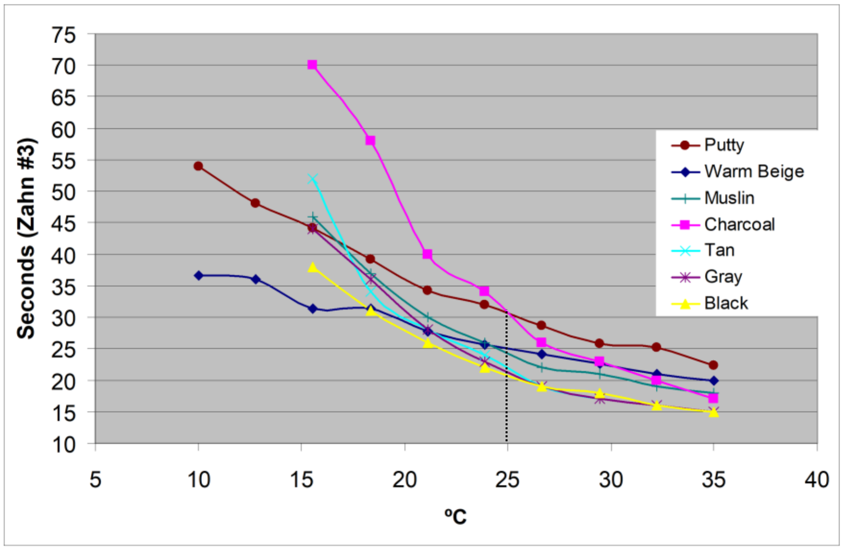

Figure 8: Paint Viscosity vs. Temperature by Color[4]

An important, but often mis-understood fact regarding viscosity is that every coating formulation has its own tempera-ture/viscosity relationship. Figure 8 shows the plots for seven colors, all of the same resin base type, and formulated for the same application. These would all be considered "the same paint" yet display a range of viscosities from 21 to 31 seconds at 25°C (77°F) and each varies quite differently over the same 10°C – 35°C temperature range.

If these are all going to be used in the same process (as they were originally intended), something will have to change to accommodate the different viscosity for each formulation. The most common adjustment is solvent addition, but this has many penalties which may include longer cure cycles, degraded finish quality, and poorer performance in the application, just to name a few. A better solution is to keep the formulation as provided by the supplier, and then adjust the temperature to arrive at the desired viscosity – in this case, 26 seconds.

Figure 9: Viscosity vs. Temperature by Color[4]

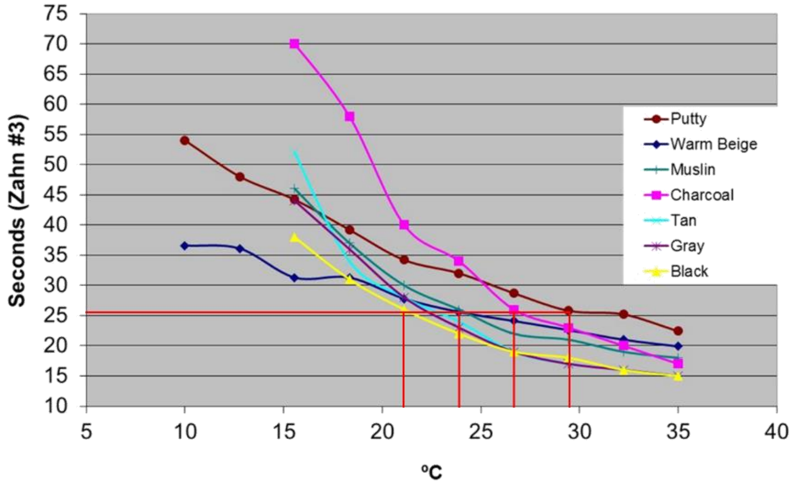

Figure 9 demonstrates this principle. To maintain a constant 26-second viscosity we must consistently deliver each paint to the point-of-application at its optimal temperature. In this example, the Black would be run at 21°C (70°F), the Muslin and Warm Beige at 24°C (75°F), the Charcoal at about 26°C (79°F), and the Putty just north of 29°C (84°F).

In short, we are using coating temperature as a tool to set and maintain our viscosity – thus making viscosity a controlled parameter in our process.

<u>The Unique Case of UV Cure Coatings</u>

UV cure coatings have been hailed as a means to reduce solvent use and to allow coating of substrates such as wood and plastic that are not conducive to oven curing. The unique case of UV cure coatings comes from the differences in their rheology, yet they exhibit many similarities to their solventborne counterparts. They are comprised of an oligomer resin that is quite viscous. To bring that viscosity down to a useable range, a monomer reducer is added. But, as with solventborne materials, this reducer affects the application and curing processes, as well as the performance of the coating on the end product. Therefore, as with solvents, it is desirable to minimize monomers in our applied formulations.

Figure 10 shows the curves for a typical UV cure coating in its pure state, and when blended with monomer reducer at 70/30 and 50/50 ratios.

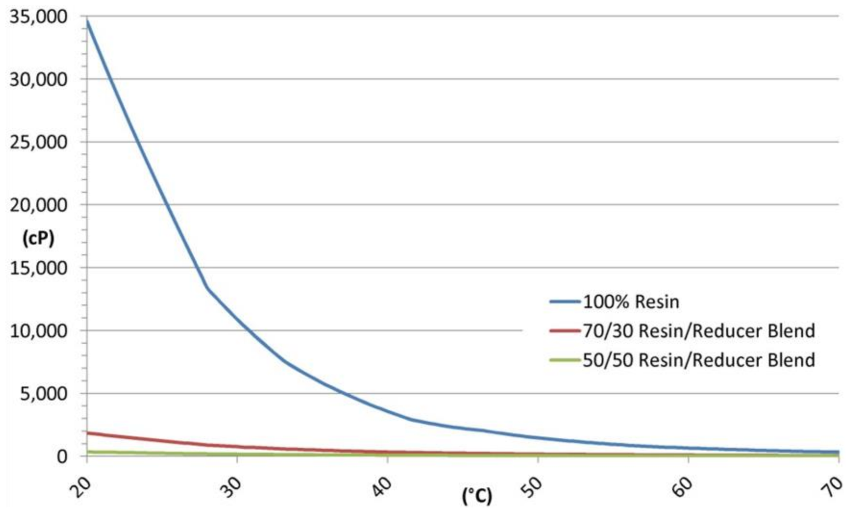

Figure 10: Viscosity of Various Concentrations of UV Cure Resin and Reducer vs. Temperature

This shows the high viscosity of the resin and the dramatic effect of temperature on that viscosity. Looking only at the normal ambient range of 20°C – 40°C (68°F – 104°F), the solventborne paint in Figure 7 above displays a 2.5:1 change in viscosity, as compared to 10:1 for this UV resin.

As with it's solventborne counterpart the viscosity of the monomer reducer is orders of magnitude lower than the resin and so, has a significant impact on the viscosity of the blend. Though the reduced curves in Figure 10 appear quite flat, this is an optical illusion caused by the large vertical scale required to display the entire 100% oligomer curve. On closer examination, these are all exponential curves and so are much easier to see and compare when we change to a logarithmic vertical scale as shown in Figure 11.

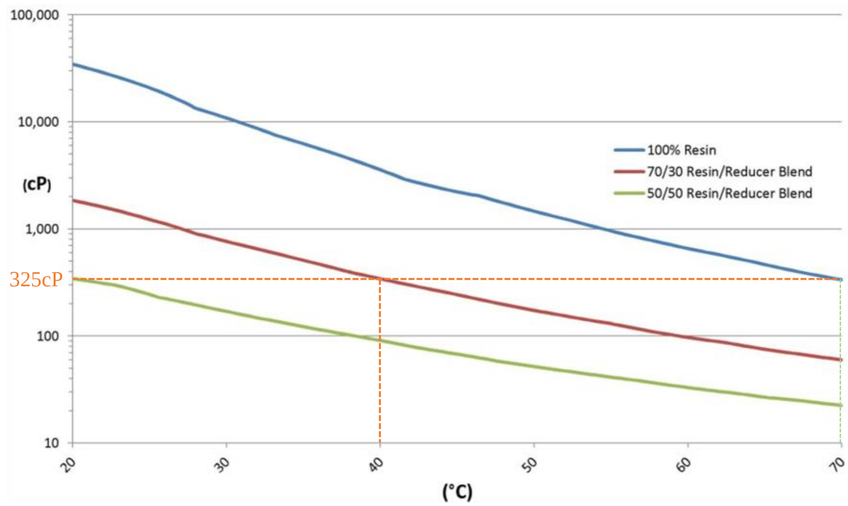

Figure 11: Viscosity of Various Concentrations of UV Cure Resin and Reducer vs. Temperature on a Logarithmic Scale

To demonstrate the similarity between solventborne and 100% solids coatings, we will make the assumption that we are substituting this 100% solids coating for the solventborne coating above in the same application process, and therefore desire to have the same 26s viscosity. A common viscosity conversion chart[5] reveals that 26s in a Zahn #4 cup is equivalent to about 325cP.

As in Figure 9 above, if we place a line at 325cP on this graph, some interesting coincidences appear. First is that the 50/50 blend is at 325cP at 20°C (68°F). Following our assumption, then, we can hold the 50/50 blend at 20°C and make a direct substitution into our process. But, as we have already demonstrated, the goal is to minimize reducer to control costs and improve performance. Following to the right we find that at 40°C (104°F), the 70/30 blend is also at 325cP. At the extreme, the 100% resin is at 325cP at 70°C (158°F) and could be used without added monomer at that temperature, but this is too hot and requires special system design considerations to protect both the parts and the operators.

Again, this shows that temperature control can be used as a tool to provide flexibility in our formulation to optimize performance without concern for a wide range of operating parameters. To demonstrate how this affects our choice of atomizer for our application, we must also look at the temperature (and therefore the viscosity) of the particles when they reach the surface of our part.

The Impact of Ambient on Particle Temperature

It is widely believed that it is important to carefully control booth temperature because it directly affects the temperature of the coating as it is being applied. On first blush, it seems a logical assumption. After all, the atomized droplets are extremely small, and there's a huge number of them, which presents a large surface area to the ambient air when compared to bulk fluid.

The reality, however, is much different.

While it is virtually impossible to measure the temperature of individual droplets in the cloud, it is fairly straightforward to calculate the change in temperature. Saint Clair Systems has developed tools to perform these calculations quickly and easily to assist coaters in better evaluating and planning their process control strategies. An example calculation is shown in Figure 12.

Coating Parameters				
Distance to Part:	10	in	254	mm
Thermal Conductivity (*k*):	2.595	BTU in/ft² hr °F	0.374	W/mK
Specific Gravity:	1.200		1.200	g/cc
Specific Heat (*Cp*):	0.500	BTU/lb °F	2.093	J/g °C
U-Value of Air:	0.2	BTU/ft² hr °F	1.136	W/m² °C
Air Temperature:	77.0	°F	25.0	°C
Inlet Paint Temp:	104.0	°F	40.0	°C

	Bell		Gun		
	min	max	min	max	
Particle Speed:	150	300	300	600	mm/s
Particle Speed:	5.91	11.81	11.81	23.62	in/s
Time to Part:	1.69	0.85	0.85	0.42	s
Particle Size (Diameter):	26	28	39	65	µm
Particle Surface Area:	2.1237E-09	2.4630E-09	4.7784E-09	1.3273E-08	m²
Particle Size (Diameter):	1.0236E-03	1.1024E-03	1.5354E-03	2.5591E-03	in
Particle Surface Area:	3.2918E-06	3.8177E-06	7.4065E-06	2.0574E-05	in²
Particle Volume:	5.6159E-10	7.0141E-10	1.8954E-09	8.7748E-09	in³
U-Value of Paint:	5069.95	4707.81	3379.96	2027.98	BTU/ft² hr °F
System U-Value:	0.20	0.20	0.20	0.20	BTU/ft² hr °F
Thermal Gain/(Loss):	-5.8061E-11	-3.3668E-11	-6.5317E-11	-9.0715E-11	BTU
Particle ΔT:	-2.6546602	-1.2325171	-0.8848693	-0.2654503	°C
Particle Temp at Part:	37.35	38.77	39.12	39.73	°C

Figure 12: Particle Temperature Change Calculations

Here we can see some critical scenarios played out together for easy comparison.

Remembering the discussion of atomization above, we noted that guns move particles toward their target at much higher speeds than do bells. According to Carlisle Fluid Technologies, bells create particles with speeds ranging from 150 – 300 mm/s, whereas guns create particles with speeds ranging from 300 – 600 mm/s — double that of the bell.[6] This means that the average time that the particles are in the air ranges from 0.42s – 1.69s. In spite of the large surface area presented to the ambient air, this is not a long time to effect a change of temperature. This is especially easy to understand when we consider the insulative properties of air, which has a U-value of just 0.2 BTU/ft² hr °F.

In this specific example, we look at the situation where the booth temperature is controlled at 25°C (77°F) and the 50-50 blend UV cure coating temperature is being held at 40°C (104°F) so as to stabilize it's viscosity for spraying. We can see that, with the high particle velocities created by the gun and resulting shorter time in the air, the coating loses between 0.27°C – 0.88°C — reaching the part still above 39°C. Even with the relatively longer time in the air caused by the lower velocities of the bell, the coating only changes by 1.2°C – 2.7°C — again in the worst case, still reaching the part above 37°C. If you are assuming that your coating is being applied at 25°C and it is actually above 37°C, you may find it very difficult to make the right decisions to keep your finish quality in spec.

This is why modern progressive coaters consider controlling coating temperature at the point of application to be more important to finish quality than controlling both temperature.

Choosing an Applicator

What you are coating, and how you are coating it are prime considerations in choosing an applicator. As we related earlier, guns are better suited to manual applications than are bells. In robotic applications, however, both have their purpose. We'll use the automobile as an example.

Why?

Because it is the "Holy Grail" of the "100% solids/UV cure coatings consortium". When we are painting cars on a production basis, we've finally "made it".

Why?

Because the very geometry of the automobile, with deep recesses and gentle, sloping surfaces, comprised of a wide variety of substrates, with the need for extremely high quality finishes on both horizontal and vertical surfaces makes it a combination of all the greatest challenges to a finishing operation.

When choosing an atomizer, the higher velocities and more directional fan pattern of a gun is considered better for "cut-in" — coating areas with deep curves like the areas around the doors, trunk, engine compartment, etc. The consistent atomization of bells make them better suited for large areas with gentle shapes where surface finish — often referred to as "Class A" — is extremely critical, like the hood, roof, trunk lid, doors, quarter panels, etc.

Likewise, it is common for Tier I suppliers to use guns for deep form parts like mirror housings, grills, etc. — where they need to drive the coating into areas where a lower velocity would be insufficient — but then to use bells for more gentle, aesthetically important parts like bezels, gas filler doors, bumpers, and facias.

In short, both applicator styles have their place and it is not uncommon to use them in combination, taking advantage of the strength of each. What is equally important to understand is that neither style can overcome the problems created when the coating being delivered to them is out of control. This is especially true with UV cure materials.

Temperature as a Tool

Using temperature as a tool to manage the viscosity fed to your atomizer of choice is especially important in UV cure coatings for several reasons. First, because UV cure coatings are 100% solids, there are no solvents to flash off to start the curing process in the application booth and slow flow out to hold the coating in place. The coating will continue to flow at the same rate until exposed to the UV source, at which point the cure is virtually instantaneous. But this works to our advantage, because the coating is 100% solids and will not "shrink" in the cure process, the wet film is applied at the same thickness as the desired dry film. This means that there is less wet coating available to flow out into a smooth contiguous coating. Therefore, coating viscosity and droplet size (atomization) must be carefully balanced and controlled, especially where Class A finishes are required, to get the proper flow-out at this lower applied volume.

Knowing that temperature remains fairly constant between the atomizer and the part changes our perspective on control at the point-of-application. This is especially true where we use elevated temperature to reduce the amount of monomer in our blend. Using the example above, where we are applying the 50/50 blend at 40°C (104°F) to maintain a low application viscosity (to allow use with a bell, for instance), a fairly small reduction in temperature will result in an increase in viscosity (due to the much steeper viscosity vs. temperature curve). If we are maintaining our booth air and part at 25°C (77°F), we can select our atomizer to allow a smooth, even coating to be applied and then depend on the cooling imparted by the substrate to increase the viscosity of the coating to hold it in place until it is cured. In short, temperature can be used in place of evaporation (flash-off) – which is especially good for vertical surfaces.

Conclusion

As we've already noted, both applicator styles have their place and it is not uncommon to use them in combination, taking advantage of the strength of each. The specific methods of atomization and delivery must be matched closely with the coating formulation, and that coating must be carefully controlled when delivered to assure that the atomizer/coating system functions properly. This is especially critical with UV cure materials.

BIBLIOGRAPHY

1 – Gun photograph provided courtesy of FreeImages.com.

2 – Bell Atomizer photograph provided courtesy of Carlisle Fluid Technologies.

3 – Paint Temperature vs. Viscosity data provided courtesy of Alsco Metals Corporation – Roxboro, NC.

4 – Paint Viscosity vs. Temperature data provided courtesy of Sherwin-Williams Corporation.

5 –Viscosity Conversion data provided courtesy of Norcross Viscosity Controls. http://web.viscosity.com/download-viscosity-conversion-tables.

6 – Bell and gun particle velocity data provided courtesy of Carlisle Fluid Technologies.

Michael R. Bonner is the Vice President of Engineering & Technology for St. Clair Systems, Inc., a leading supplier of process temperature and viscosity control equipment for industrial fluid processing systems.

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